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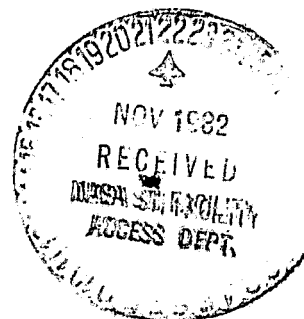


## Technical Memorandum 83969

# An Evaluation of the NASA/GSFC Barnes Field Spectral Reflectometer Model 14-758, Using Signal/Noise as a Measure of Utility

Robin Bell and Mark L. Labovitz

JULY 1982



National Aeronautics and  
Space Administration

Goddard Space Flight Center  
Greenbelt, Maryland 20771

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ABSTRACT

A Barnes field spectral reflectometer which collected information in 373 channels covering the region from 0.4 to 2.5 micrometers ( $\mu\text{m}$ ) was assessed for signal utility. A band was judged unsatisfactory if the probability was 0.1 or greater that its signal to noise ratio was less than eight to one. For each of the bands the probability of a noisy observation was estimated under a binomial assumption from a set of field crop spectra covering an entire growing season. A 95% confidence interval was calculated about each estimate and bands whose lower confidence limits were greater than 0.1 were judged unacceptable. As a result, 283 channels were deemed statistically satisfactory. Excluded channels correspond to portions of the electromagnetic spectrum (EMS) where high atmospheric absorption and filter wheel overlap occur. In addition, the analyses uncovered intervals of unsatisfactory detection capability within the blue, red and far infrared regions of vegetation spectra. From the results of the analysis it was recommended that 90 channels monitored by the instrument under consideration be eliminated from future studies. These channels are tabulated and discussed. An appendix of the signal to noise ratio averages and standard deviations for each channel is included.

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# AN EVALUATION OF THE NASA/GSFC BARNES FIELD SPECTRAL REFLECTOMETER MODEL 14-758, USING SIGNAL/NOISE AS A MEASURE OF UTILITY

## INTRODUCTION

The continual appearance of new radiometers and reflectometers occurring with rapid changes in microprocessors and related electronics produces a pressure on the researcher to get the instrument "into the field" and collecting data. However great this pressure, it is important that performance of any instrument be verified prior to substantive data collection. Unknown performance idiosyncrasies could potentially invalidate conclusions drawn from analyses of data collected with such unexamined equipment and thereby waste valuable resources.

We examine in this study the GSFC Barnes Model 14-758 field spectral reflectometer. Specifically, a value of the noise level synchronously recorded with reflectance for each channel monitored is assessed. In this study the instrument's utility is defined as the strength of the signal at each channel for each spectral interval. We propose a method to assess utility, and then apply the method in an analysis wherein utility is defined within the overall field measurement setting, and where the field setting is the measurement of agricultural crops.

## FIELD MEASUREMENT ENVIRONMENT

The target-instrument system may be compartmentalized into components potentially causing variation during the evaluation of a particular field instrument. These sources of potential variation can be conveniently grouped as sources (1) internal to the instrumentation, (2) external to the instrumentation, and (3) arising from the interactions of internal and external sources. We will briefly describe each of these groups, starting with the latter.

The interaction of internal and external sources is mentioned largely for completeness, and represents the fact that changes in components of subsystems often do not have strictly independent and additive effects upon the output of the system. For example, an interaction source of variation

would be present if the output from the sensing system (be it digital counts or radiance) was among other things, not only a function of the solar flux and type of detector, but also a function of a specific combination of these two factors.

Measurements in the field are subject to meteorological variation such as cloud cover and precipitation. Where the latter can result in great variation in observations made on successive days, cloud cover can contribute to data variation on the time scale of seconds. Other sources of variation external to the instrument result from changes in the target (field plot). These can also be a result of meteorological changes, such as changes in the target structure related to winds (short term) or can result from a progressive change in a target over a growing season (long term). The solar illumination flux, with energy varying over wavelength, must also be taken in consideration.

Internal sources of variation include scan time, spectral resolution, calibration of the instrument, detector type and specific wavelength interval (Holmes, 1970).

The internal sources of variation combine to determine the sensitivity of an instrument. The sensitivity is largely defined by spectral resolution and detector type of the instrument in question. The spectral resolution is linked to the filter system used. Various methods exist for isolating desired portions of the electromagnetic spectrum (EMS). Whether a prism or interference filters are used to selectively eliminate certain portions of the EMS, it is important to understand the specifications and thereby determine how discrete the spectral elements of the instrument truly are. Once isolated, the desired spectral range is passed on to the detector. The detector is the pivot point of any radiometer, as other design specifications, such as cooling and effective spectral coverage must accommodate the detector used (Holter, 1970).

## EXPERIMENT

In this experiment we evaluate a new field radiometer specifically for sensitivity. Using the output of a sensing system, sensitivity in this study is viewed as the utility of the signal from a spectral

channel, and is operationally defined below as a function of the signal to noise ratio (S/N). The instrument, a Barnes Model 14-758 field spectral reflectometer, is described in the following section. The experiment analyzed observations from the field environment in which the instrument was used, so the targets were field crops - corn, wheat and soybean plots - located on the USDA's Beltsville Agricultural Research Center, Beltsville, MD. Since the experiment was not designed, i.e., we were working with previously collected data, the sources of unwanted variation were treated by holding them constant. This was accomplished by only using data collected under similar conditions; sunny, relatively still days between 10 a.m. and 2 p.m. solar time, with the instrument mounted on a cherry picker, nadir pointing and seven meters above the target. A white reflectance standard was used to calibrate the readings. (The instrument offers a sky-tube as optional reference.) In short, the study was designed to examine the instrument's reliability with respect to obtaining what the authors considered a useable signal over the various wavelengths monitored.

## INSTRUMENTATION

The Barnes Radiometer is a self-calibrating spectral scanner with spectral resolution on the order of three percent of the wavelength (Barnes Engineering Company, 1976). It is designed to operate over a range of 0.4 to 2.5  $\mu\text{m}$ . Incoming energy for shorter and longer wavelengths is extremely attenuated by atmospheric effects in addition to the initially lessened incoming energy outside of this interval (Figure 1). Specifically in the Barnes instrument, differing wavelength intervals over a 0.3905-2.5355  $\mu\text{m}$  segment of the EMS are effected by a rotating, continuously variable filter. This filter which consists of three segments, has 373 filter positions of varying band width. Incoming energy is separated by a rotating chopper blade that revolves once every 200 milliseconds so that the reference and the sample are each viewed five times within one second. The resulting 5 Hz pulses are recorded at a 400 Hz rate to maintain at approximately less than one percent any confusion between sample and reference views. The filter position stepper motor is driven at the rate of one step every 200 milliseconds so that a new filter position is reached synchronously with the 5 Hz chopper. This filtered energy is focused upon a lead sulfide detector, cooled to 0°C (Barnes



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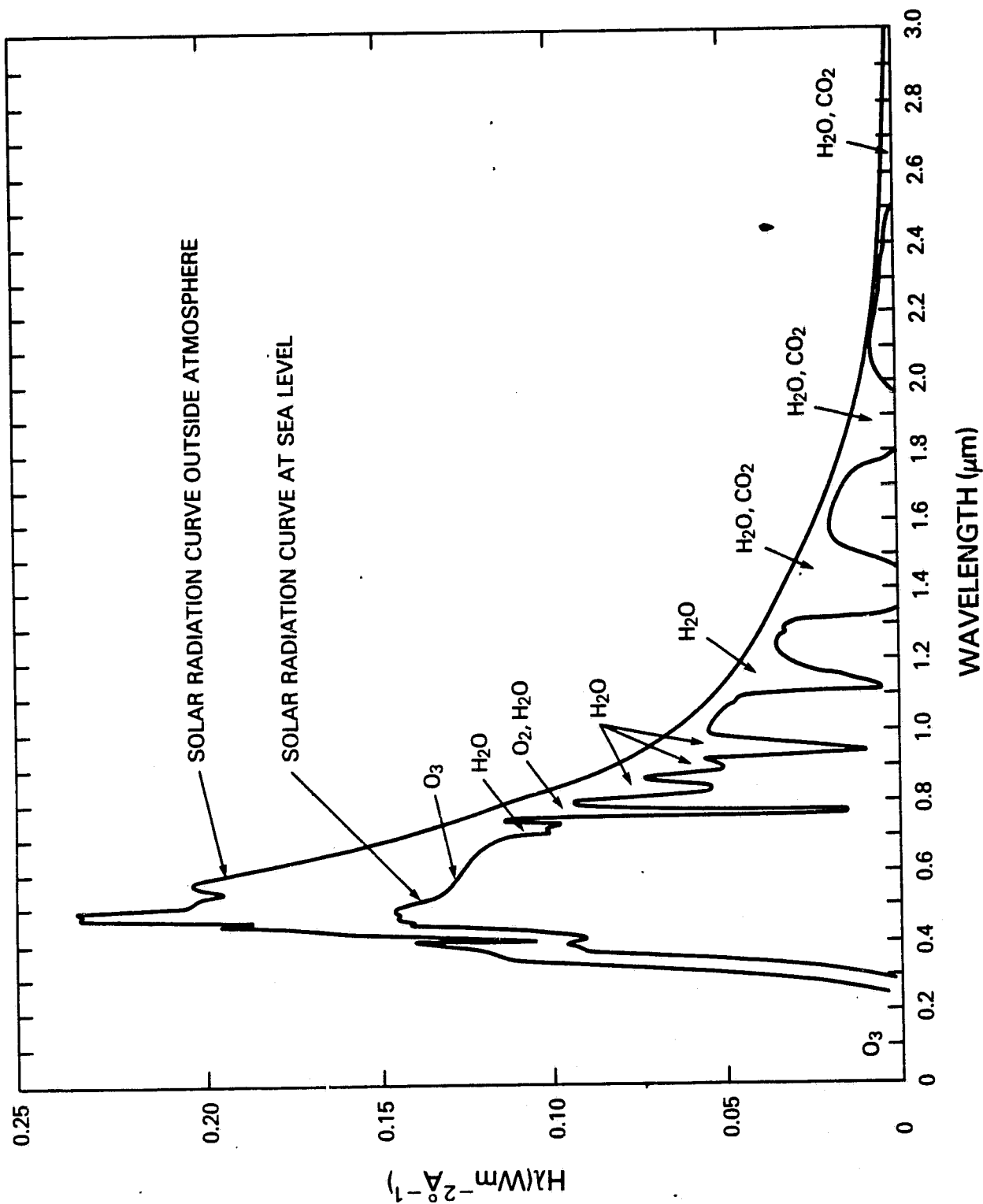


Figure 1. Atmospheric Absorption of Solar Flux (after Valley, 1965)

Engineering Company, 1976). The wavelengths monitored are separated into approximately four nanometer intervals for the first two segments, and 13 nanometer intervals for the third filter wheel segment (Table 1). Specified wavelengths are the midpoints of the filter positions and there is considerable overlap. At the two points in the spectrum monitored where there is a filter wheel segment change, there is overlap in spectral coverage. These regions are from 0.6523  $\mu\text{m}$  to 0.7177  $\mu\text{m}$ , and from 1.3744  $\mu\text{m}$  to 1.4145  $\mu\text{m}$ .

## FORMAL ANALYSIS SETTING

### Definition of Sensitivity

As stated previously, the purpose of this work is to determine the utility of the 373 channels of the Barnes instrument by assessing channel sensitivity. Sensitivity is defined here as a function of the S/N monitor of useable signal, which was recorded by the reflectometer at the same time as the reflectance values. As the recorded S/N value was the variable of choice for this analysis, and the authors were unable to determine how the instrument recorded variable was derived, various regression models were employed in an attempt to estimate the strength and form of any relationship between instrument recorded S/N data and a more generally accepted method of computation. From the original data (defined below, refer to Data section), a S/N data set was calculated using

$$\bar{Y}_{\text{reflectance } \lambda} / \sigma^2_{\text{reflectance } \lambda} = S/N_{\lambda}$$

where  $\bar{Y}_{\text{reflectance } \lambda}$  = mean of the reflectance values for wavelength  $\lambda$

and  $\sigma^2_{\text{reflectance } \lambda}$  = variance of the reflectance values for wavelength  $\lambda$ .

The  $S/N_{\lambda}$  value was used as the dependent variable in the regressions, with the Barnes recorded S/N for the respective wavelengths as the predictor variable. One hundred and twenty average reflectance values and their respective average variances were used in the models. Channels corresponded to the lowest through the highest machine recorded S/N values. From plots of the calculated S/N against the Barnes recorded S/N and from residual plots from linear models, it was determined that a non-linear asymptotic curve best described the relationship between the two S/N variables (Figure 2).

Table 1

**Barnes Filter Positions and Their Respective Mid Point Target Wavelengths  
(in Nanometers)**

**Channels Performing Unsatisfactorily (S/N <8) Asterisked  
Filter Segment Spectral Overlap  $\alpha$**

Filter Position	Mid Point $\lambda$	Filter Position	Mid Point $\lambda$	Filter Position	Mid Point $\lambda$	
5*	390.5	45	535.9	85 $\alpha$	681.4	
6*	394.1	46	539.6	86* $\alpha$	685.0	
7*	397.8	47	543.2	87* $\alpha$	688.6	
8*	401.4	48	546.8	88 $\alpha$	692.9	
9*	405.0	49	550.5	89 $\alpha$	695.9	
10*	408.7	50	554.1	90 $\alpha$	699.5	
11*	412.3	51	557.7	91 $\alpha$	703.2	
12*	415.9	52	561.4	92 $\alpha$	706.8	
13*	419.6	53	565.0	93 $\alpha$	710.4	
14*	423.2	54	568.6	94 $\alpha$	714.1	Filter Segment 1
15*	426.8	55	572.3	95 $\alpha$	717.7	
16*	430.5	56	575.9	105* $\alpha$	653.5	Filter Segment 2
17*	434.1	57	579.6	106* $\alpha$	657.5	
18*	437.7	58	583.2	107* $\alpha$	661.5	
19*	441.4	59	586.8	108 $\alpha$	665.5	
20*	445.0	60	590.5	109 $\alpha$	669.5	
21*	448.7	61	594.1	110 $\alpha$	673.6	
22*	452.3	62	597.7	111 $\alpha$	677.6	
23*	455.9	63	601.9	112 $\alpha$	681.6	
24*	459.6	64	605.0	113 $\alpha$	685.6	
25*	463.2	65	608.6	114 $\alpha$	689.6	
26*	466.8	66	612.3	115 $\alpha$	693.6	
27*	470.5	67	615.9	116 $\alpha$	697.6	
28*	474.1	68	619.5	117 $\alpha$	701.6	
29*	477.7	69	623.2	118 $\alpha$	705.6	
30*	481.4	70	626.8	119 $\alpha$	709.6	
31*	485.0	71	630.5	120 $\alpha$	713.6	
32*	488.7	72	634.1	121 $\alpha$	717.6	
33*	492.3	73	637.7	122	721.6	
34*	495.9	74	641.4	123	725.6	
35*	499.6	75	645.0	124	729.6	
36*	503.2	76	648.6	125	733.6	
37	506.8	77* $\alpha$	652.3	126	737.6	
38*	510.5	78* $\alpha$	655.9	127	741.6	
39	514.1	79* $\alpha$	659.5	128	745.6	
40	517.7	80* $\alpha$	663.2	129	749.6	
41	521.4	81* $\alpha$	666.8	130	753.7	
42	528.6	82* $\alpha$	670.5	131	757.7	
43	528.6	83* $\alpha$	674.1	132	761.7	
44	532.3	84 $\alpha$	677.7	133	765.7	

Table 1 (continued)

Channels Performing Unsatisfactorily ( $S/N < 8$ ) Asterisked  
Filter Segment Spectral Overlap  $\alpha$

Filter Position	Mid Point $\lambda$	Filter Position	Mid Point $\lambda$	Filter Position	Mid Point $\lambda$
134	769.7	177	941.9	220	1114.1
135	773.7	178	945.9	221	1118.1
136	777.7	179	949.9	222	1122.1
137	781.7	180	953.9	223	1126.1
138	785.7	181	957.9	224	1130.1
139	789.7	182	961.9	225	1134.1
140	793.7	183	965.9	226	1138.1
141	797.7	184	969.9	227	1142.1
142	801.7	185	973.9	228	1146.1
143	805.7	186	977.9	229	1150.1
144	809.7	187	981.9	230	1154.2
145	813.7	188	985.9	231	1158.2
146	817.7	189	989.9	232	1162.2
147	821.7	190	994.0	233	1166.2
148	825.7	191	998.0	234	1170.2
149	829.7	192	1002.0	235	1174.2
150	833.8	193	1006.0	236	1178.2
151	837.8	194	1010.0	237	1182.2
152	841.8	195	1014.0	238	1186.2
153	845.8	196	1018.1	239	1190.2
154	849.8	197	1022.0	240	1194.2
155	853.8	198	1026.0	241	1198.2
156	857.8	199	1030.0	242	1202.2
157	861.8	200	1034.0	243	1206.2
158	865.8	201	1038.0	244	1210.2
159	869.8	202	1042.0	245	1214.2
160	873.8	203	1046.0	246	1218.2
161	877.8	204	1050.0	247	1222.2
162	881.8	205	1054.0	248	1226.2
163	885.8	206	1058.0	249	1230.2
164	889.8	207	1062.0	250	1234.3
165	893.8	208	1066.0	251	1238.3
166	897.8	209	1070.0	252	1242.3
167	901.8	210	1074.1	253	1246.3
168	905.8	211	1078.1	254	1250.3
169	909.8	212	1082.1	255	1254.3
170	913.9	213	1086.1	256	1258.3
171	917.9	214	1090.1	257	1262.3
172	921.9	215	1094.1	258	1266.3
173	925.9	216	1098.1	259	1270.3
174	929.9	217	1102.1	260	1274.3
175	933.9	218	1106.1	261	1278.3
176	937.9	219	1110.1	262	1282.3

Table 1 (continued)

Channels Performing Unsatisfactorily (S/N < 8) Asterisk  
Filter Segment Spectral Overlap  $\alpha$

Filter Position	Mid Point $\lambda$		Filter Position	Mid Point $\lambda$		Filter Position	Mid Point $\lambda$
263	1286.3		315	1502.3		358	2057.7
264	1290.3		316	1515.2		359	2070.6
265	1294.3		317	1528.2		360	2083.5
266	1298.3		318	1541.1		361	2096.4
267	1302.3		319	1554.0		362	2109.3
268	1306.3		320	1566.9		363	2122.2
269	1310.3		321	1579.8		364	2135.2
270	1314.3		322	1592.7		365	2148.1
271	1318.4		323	1605.6		366	2161.0
272	1322.4		324	1618.6		367	2173.9
273	1326.4		325	1631.5		368	2186.8
274	1330.4		326	1644.4		369	2199.7
275	1334.4		327	1657.3		370	2212.7
276	1338.4		328	1670.2		371	2225.6
277	1342.4		329	1683.1		372	2238.5
278	1346.4		330	1696.1		373	2251.4
279	1350.4		331	1709.0		374	2269.3
280	1354.4		332	1721.9		375	2277.2
281	1358.4		333	1734.8		376	2290.1
282	1362.4		334	1747.7		377	2303.1
283	1366.4		335	1760.6		378	2316.0
284*	1370.4		336	1773.5		379*	2328.9
285* $\alpha$	1374.4		337	1786.5		380*	2341.8
286* $\alpha$	1378.4		338	1799.4		381*	2354.7
287* $\alpha$	1382.4		339*	1812.3		382*	2367.6
288* $\alpha$	1386.4		340*	1825.2		383*	2380.5
289* $\alpha$	1390.4		341*	1838.1		384*	2393.5
290* $\alpha$	1394.5		342*	1851.0		385*	2406.4
291* $\alpha$	1398.5		343*	1863.9		386*	2419.3
292* $\alpha$	1402.5		344*	1876.9		387*	2432.2
293* $\alpha$	1406.5		345*	1889.8		388*	2445.2
294* $\alpha$	1410.5	Filter Segment 2	346*	1902.7		389*	2450.0
295* $\alpha$	1414.5		347*	1915.6		390*	2471.0
305* $\alpha$	1373.2	Filter Segment 3	348*	1928.5		391*	2483.9
306* $\alpha$	1386.1		349*	1941.4		392*	2496.8
307* $\alpha$	1399.0		350*	1956.6		393*	2509.7
308* $\alpha$	1411.9		351	1967.3		394*	2522.6
309 $\alpha$	1424.8		352	1980.2		395*	2535.5
310 $\alpha$	1437.8		353	1993.1			
311	1450.7		354	2006.0			
312	1463.6		355	2018.9			
313	1476.5		356	2031.8			
314	1489.4		357	2044.8			

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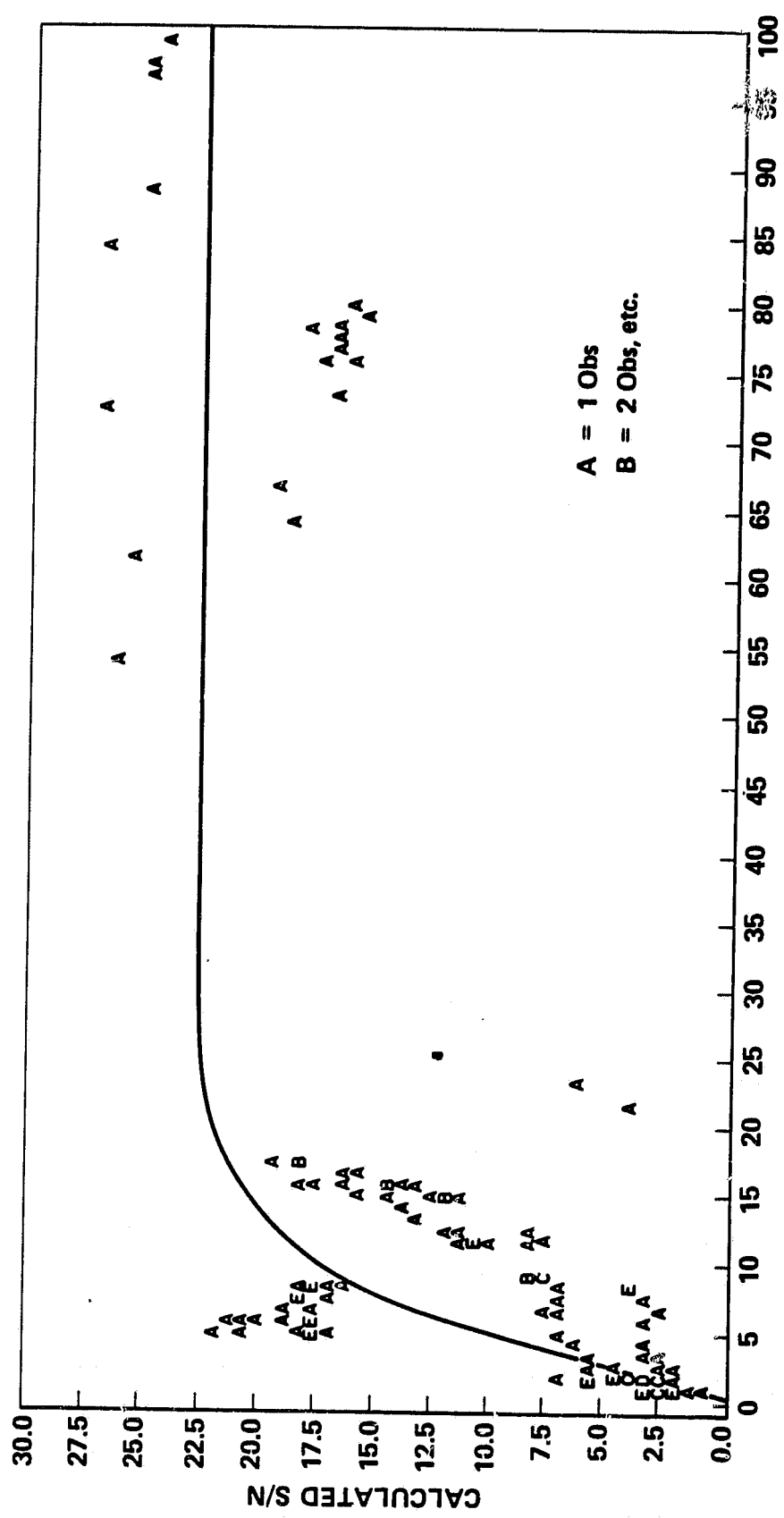


Figure 2. Non-linear Asymptotic Curve

The model

$$S/N_{\text{calc}} = A - B \left( e^{-C \cdot S/N_{\text{bar}}} \right)$$

where  $S/N_{\text{calc}}$  = calculated S/N

$S/N_{\text{bar}}$  = Barnes recorded S/N

is highly significant with an F ratio of  $>244$ . The correlation coefficient between the recorded S/N and the calculated S/N is .74659, significant for  $\alpha < .01$ .

From Figure 2 it can be seen that while for larger  $S/N_{\text{bar}}$  values the  $S/N_{\text{calc}}$  is highly overestimated, the lower S/N values correspond almost one to one. We therefore feel justified in using the recorded S/N as representative of the signal strength; any error due to estimation would tend to favor conservatism in channel assessment of sensitivity.

A S/N value of eight to one was the minimum the authors considered an acceptable level, as the poorest performance anticipated is near 10 for a one percent reflective target (Barnes Engineering Company, 1976).

For any individual channel we have the following operational definition.

$$S/N < 8:1 = \text{bad data} \equiv B$$

$$S/N \geq 8:1 = \text{good data} \equiv G.$$

If we assign the value 1 to a bad observation and the value 0 to a good observation, then the random variable  $X$  has a state space  $S$  which is a set that consists of two values  $\{0,1\}$ . The probability space defined on  $X$  and  $S$  is likewise a two element set,  $\{p,q\}$  for any  $\lambda$ , where  $p = \Pr \{B\} = P(X=1)$ , the probability of getting an unacceptable observation ( $0 \leq p \leq 1$ ) and  $q = \Pr \{G\} = P(X=0) = 1-p$ , the probability of getting an acceptable observation. Under the assumption that  $p$  remains constant for each measure of the S/N from a given band and that each determination of the acceptability of the S/N is independently measured,  $X$  is known as a Bernoulli trial and the probability structure can be summarized as

$$P(X=x) = p^x q^{(1-x)} \quad (x=0,1) \quad \text{for any } \lambda.$$

A reliable channel was operationally defined, by the authors, as one which would give an acceptable S/N for 90 percent or greater of the observations. This yields the following null and alternative hypotheses:

$$H_0: p_\lambda \leq .1 \implies \text{channel is satisfactory}$$

$$H_1: p_\lambda > .1 \implies \text{channel is unsatisfactory.}$$

Since  $\hat{p}_\lambda$  is a parameter, we must estimate it. The maximum likelihood estimate of  $p_\lambda$  is formed as follows, if there are  $n$  observations of  $X$ , then

$$\hat{p}_\lambda = \frac{n_{\text{zero}}}{n} 0 + \frac{n_{\text{one}}}{n} .1,$$

where

$$n_{\text{zero}} = \text{number of times } X=0 \text{ for channel } \lambda,$$

$$n_{\text{one}} = \text{number of times } X=1 \text{ for channel } \lambda, \text{ and}$$

$$n = n_{\text{zero}} + n_{\text{one}}$$

Then using normal approximation theory for the distribution of  $\hat{p}_\lambda$ , we construct a 95 percent confidence interval about the point estimate of  $\hat{p}_\lambda$ . We define a channel as unreliable if its 95 percent confidence interval does not include 0.1.

### Data

A total of 480 scans of 373 channels each were used. From original data sets of soybean with 160 scans, wheat with 195, and corn with 182 spectral scans (each scan covering 373 channels), data sets of 160 scans were selected for each crop to balance the design. Scans were eliminated by use of a random number generator.

All three crop data sets span the growing season, with spectral readings from youngest plants through progressively maturing plants. Observations spanning this varying canopy closure were used so that conclusions concerning reliability of a specific band were as general as possible over the entire growing season.

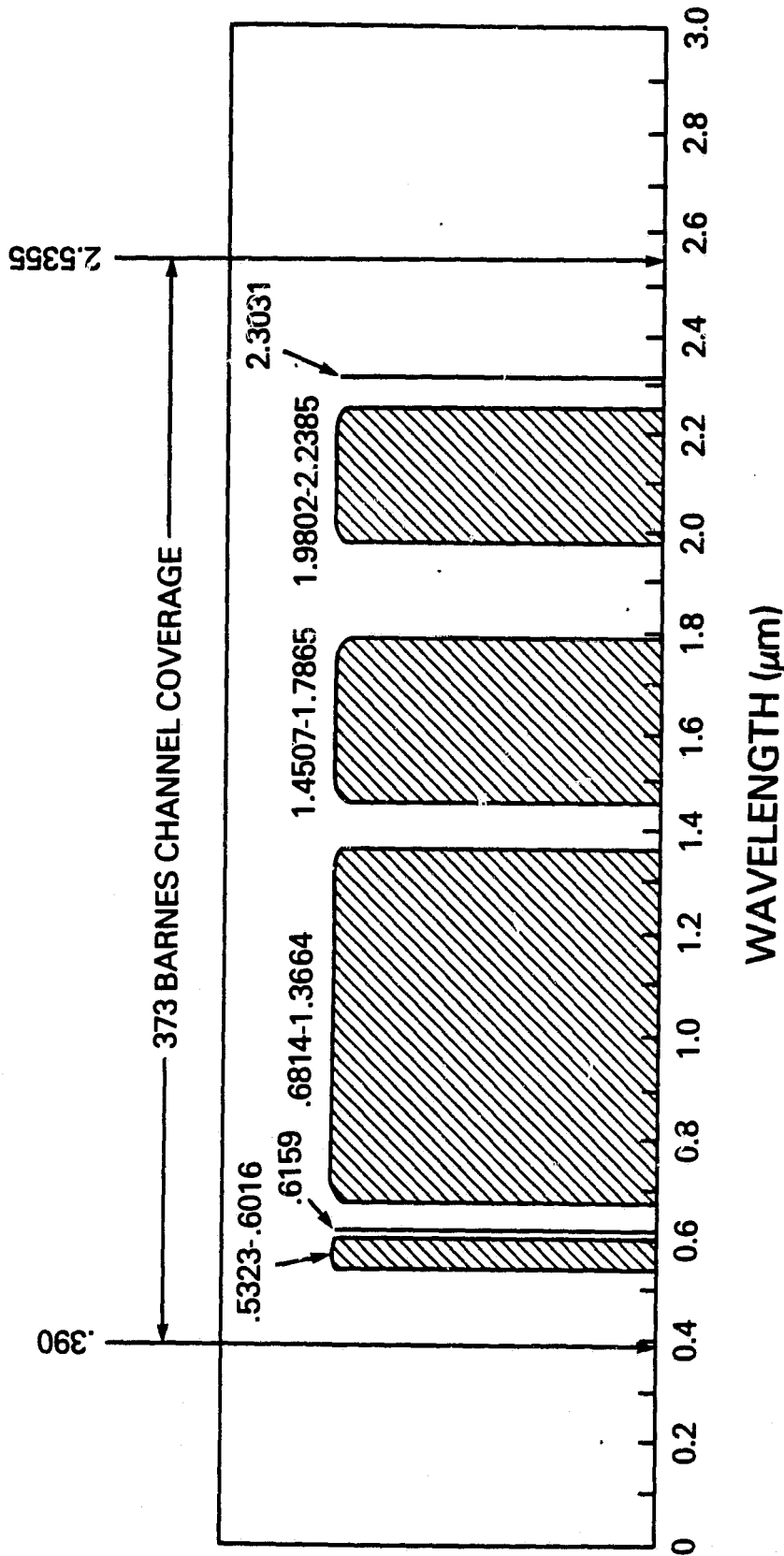


Because our model requires that  $p_\lambda$  remain constant over the growing season and across crops, a two way analysis of variance was performed. The levels for the crop factor were wheat, corn and soybean. The levels for the time factor consisted of 20 time intervals, each composed of eight consecutive scans. This design yielded eight observations of S/N per crop-time interval combination which were used to estimate  $p_\lambda$  for this examination of constancy. There was no significant difference in the estimate of  $p_\lambda$  over the eight time intervals. From the results of the analysis, we therefore concluded that  $p_\lambda$  was constant over the growing season, but varied over the crop factor. Upon further examination, it was concluded that  $p_\lambda$  remained constant across wheat and soybean but differed for corn. Therefore, the analysis of reliability proceeded as two separate analyses, one for wheat and soybean with 320 observations per channel and the second for corn with 160 observations per channel.

## RESULTS AND DISCUSSION

Table 1 shows the channels for which we rejected the null hypothesis and accepted the alternate,  $p_\lambda > .1$ . These channels as per our definition are considered unsatisfactory. In order to be considered unreliable a channel had to be unreliable for the estimate of  $p$  using the combined soy-wheat data and the corn data. Appendix A gives the 95 percent confidence interval for  $p$  for each channel for the soybean-wheat combination and corn separately, and Appendix B lists the average S/N and standard deviation for each channel.

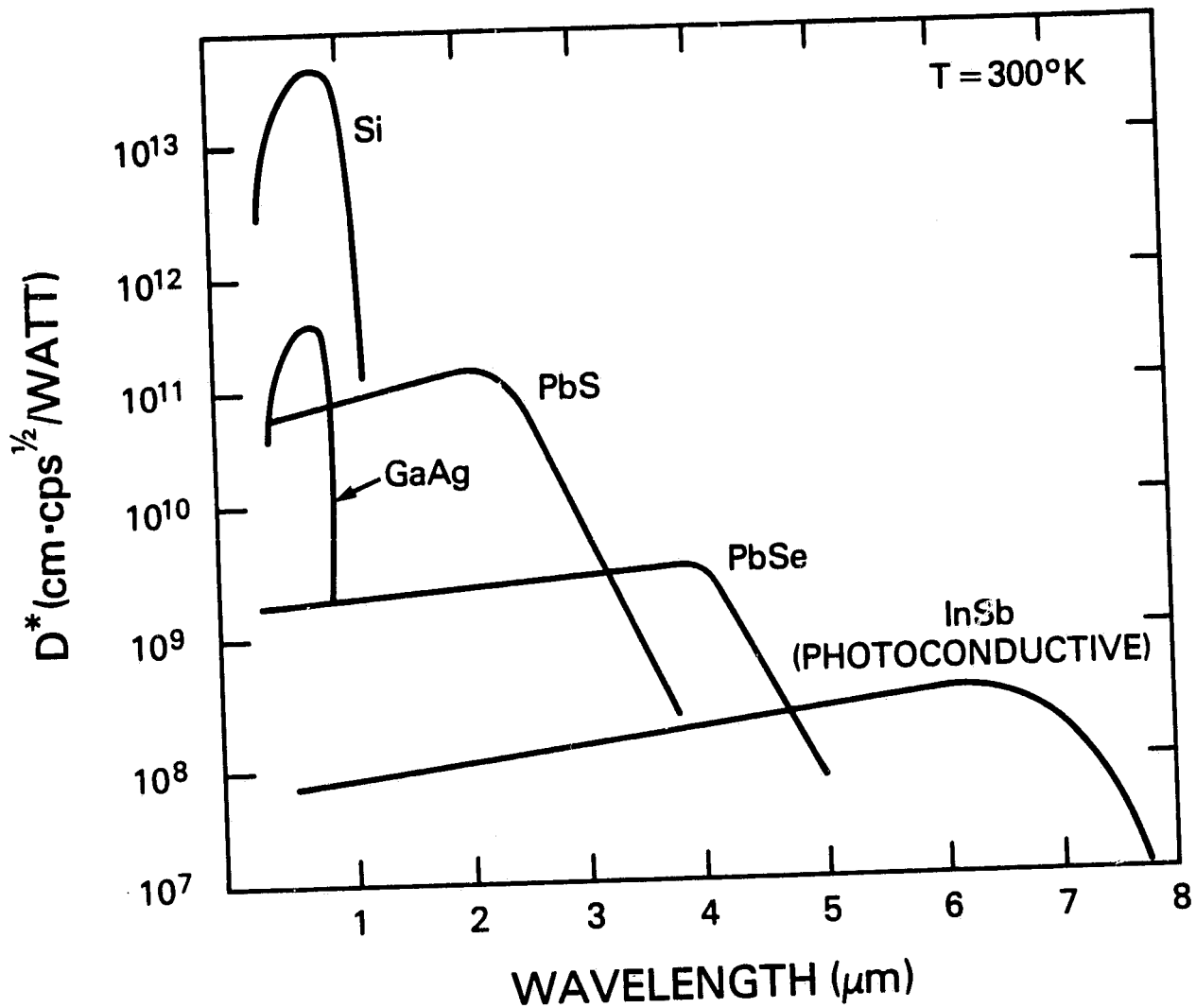
Looking at the unreliable bands as groups or regions, the analysis showed many channels at the shorter wavelengths, (0.39 – 0.69  $\mu\text{m}$ ), those centered around 1.4  $\mu\text{m}$  and 1.8 – 1.95  $\mu\text{m}$ , and all wavelengths longer than 2.3289  $\mu\text{m}$  to be unsatisfactory. Regions of unreliable bands are displayed graphically in Figure 3 and summarized in Table 2, which also lists the utility (for vegetation) and source(s) of unreliability for each region. To explain poor instrument performance at the shortest, pigment absorbing wavelengths, it is necessary to return briefly to a continuation of instrument discussion. Certain detectors are more or less effective over different portions of the electromagnetic spectrum (Figure 4), and detectors used in the visible region are quite different from those used in



Regions Shown to be Statistically Reliable 90% of the Time  $\alpha = .05$   
(Specific channels of failure within the filter wheel overlap intervals are not denoted in this diagram.)

Figure 3. Spectral Coverage of the Barnes Reflectometer

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$$D^* = A^{1/2} / P_N \text{ (cm-cps}^{1/2} / \text{watts)}$$

where

$A$  = Area of the Detector in  $\text{cm}^2$

$P_N$  = Noise Equivalent Power in  $\text{watts/cps}^{1/2}$

Figure 4. Detectivity Normalized to Unit Area and Bandwidth  
(after Potter and Eisenman, 1962)

Table 2

Summary Table of Unsatisfactory Regions

Filter Position	Wavelength ( $\mu\text{m}$ )	Potential Information (after Tucker, 1978)	Problem
5-36, 38	.3905-.5032, 5105	direct in vivo carotenoid and chlorophyll sensitivity	detector
77-83	.6523-.6741	direct in vivo chlorophyll sensitivity	detector/filter wheel overlap/ low vegetative reflectance
86-87	.6850-.6886	"	"
105-107	.6535-.6615	"	"
284-308	1.3704-1.4119	direct in vivo foliar water sensitivity	atmospheric absorption/ filter wheel overlap
330-350	1.8123-1.9566	"	atmospheric absorption
379-395	2.3289-2.5355	"	instrument design (detector?)

the IR although there is overlap of detector capability. There are two major groups of detectors employed in monitoring the agricultural region of the EMS, photoemissive for the visible, and photon counters for longer wavelengths, both of which work through the energy of incoming photons. In photodetectors, or photon counters, the electrons which react with incoming photons are bound into the sensitive element. Free charge carriers are produced and electrical properties that depend on the concentration of these free carriers are then monitored (Holter, 1970). As stated, this type of detector functions best in the IR. Within the photoconductor detector group, wavelength sensitivity varies, with some capability overlapping into the visible (Figure 4). For the shortest wavelengths monitored by photoconductors the Si detector is preferable, but in the near IR a PbS detector is more sensitive (Potter and Eisenman, 1962). The decreasing performance of a PbS detector in the shorter wavelengths becomes obvious when viewing Figure 4. Additionally, as the detector in the Barnes is cooled to approximately  $0^{\circ}\text{C}$ , its effectiveness peaks at about  $2.5 \mu\text{m}$  (Potter and Eisenman, 1962).

Thus, the unreliability of channels monitoring wavelengths shorter than  $0.5\ \mu\text{m}$  (the first 30 channels) is inherent to the Barnes instrument. Problems appear to be uncorrelated with atmospheric interference, as there are wide windows in the atmosphere from  $0.39$  to  $0.70\ \mu\text{m}$ , and the solar curve indicates similar incoming energy levels at both  $0.39\ \mu\text{m}$  and  $0.83\ \mu\text{m}$  (Figure 1). By incorporating a continuously variable filter into the design, the Barnes reflectometer integrates a differing portion of the incoming solar energy curve at each wavelength; spectral intervals are proportional to wavelength. However from the solar irradiance curve, there appears to be adequate incoming energy between  $0.35\ \mu\text{m}$  and  $0.7\ \mu\text{m}$  to compensate for the shorter spectral intervals. The presence of pigment absorption in the shorter (visible) wavelengths is a factor that also weakens performance. Where low target reflectance is combined with lowered detector sensitivity the overall S/N often falls to a low, non-utilitarian value (Figure 5).

Though inappropriate detector and low target reflectance do explain the unsatisfactory visible performance, in the  $0.65\ \mu\text{m}$  -  $0.69\ \mu\text{m}$  region there is also an area of filter wheel overlap (Table 1). The latter point is quite likely coincidental, but should none the less be noted.

The filter has two regions of overlapping bands (Figure 5, Table 1). The first region of overlap, the pigment absorption region, has already been mentioned. The second region, from  $1.37\ \mu\text{m}$  to  $1.44\ \mu\text{m}$ , coincides with the second major area of poor performance, and also falls across a water vapor and carbon dioxide absorption curtain centered at  $1.4\ \mu\text{m}$  (Figure 1). These bands potentially carry information on vegetative water content, but are normally considered unsatisfactory for field work due to extreme atmospheric attenuation. In any case, for data from channels in the  $1.37$  -  $1.44\ \mu\text{m}$  region, caution should be practiced if utilized in any analyses.

The next region of unsatisfactory performance falls from  $1.81\ \mu\text{m}$  to  $1.95\ \mu\text{m}$ , and also coincides with atmospheric absorption related to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  (Figure 1). This atmospherically attenuated region, as well as the former region are poor portions of the EMS for monitoring of vegetation in the field. As it is unlikely that any instrument could offer satisfactory field performance over these

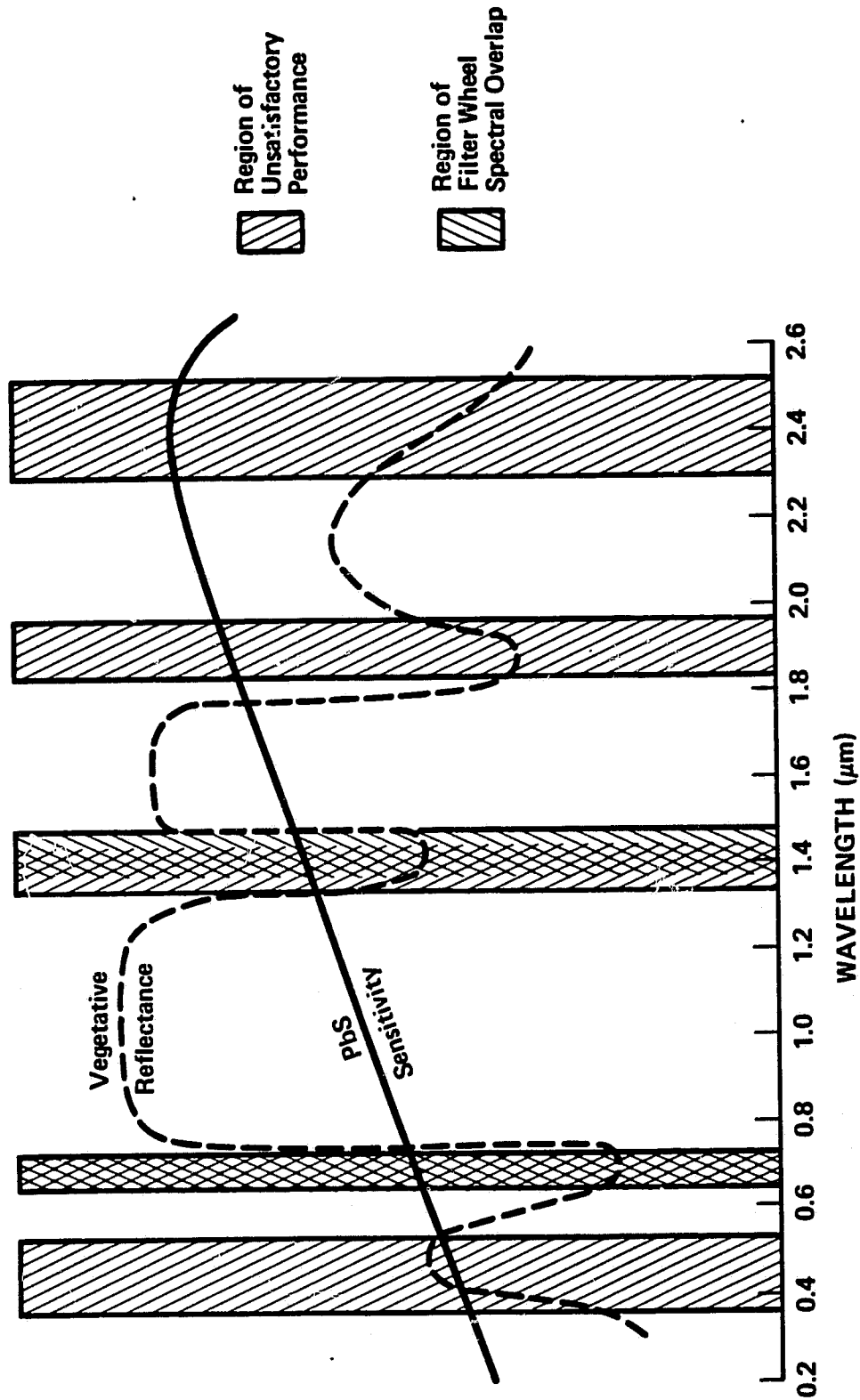


Figure 5. Comparison of Vegetative Reflectance and PbS Detector Sensitivity with Regions of Spectral Overlap and Unsatisfactory Performance

spectral intervals since high variance in the data would generally mask any useful information, the channels monitoring these intervals should be used with discretion.

The unsatisfactory performance in the region from  $2.3289\ \mu\text{m}$  to  $2.5355\ \mu\text{m}$  is related to the amount of incoming energy over a variable solar irradiation flux. As was previously indicated, a continuously variable filter alters the spectral bandwidth in proportion to wavelength in another attempt to compensate for variable solar irradiance at the ground level, specifically compensating for the lower energy in the longer wavelengths. According to Barnes documentation, the product of irradiance and responsivity is lowest at the ends of the region being used. The worst S/N for the target signal anticipated for a 100 percent reflective target is 1000 in full sunlight for  $2.4\ \mu\text{m}$ , or about 50 for a five percent reflective target (Barnes Engineering Company, 1976). This figure is valid when excluding atmospheric attenuation. However, from Figure 1 it can be seen that atmospheric absorption is not the problem at  $2.4\ \mu\text{m}$ , but rather the lowered amount of incoming energy. This supposedly worst case representation has been found to be off by an order of magnitude from the S/N recorded by the instrument.\* Consistently the wavelengths at the shorter and longer ends of the spectral range used show S/N values of less than eight.

In addition to adjusted bandwidth intervals, the Barnes reflectometer attempts to compensate for lessened irradiance in the longer wavelengths monitored by using the responsivity inherent in a PbS detector (Figure 4). From our analyses, the endeavor is unsuccessful. Therefore, data from the longest wavelength block of unsatisfactory channels ( $2.3289\ \mu\text{m}$  to  $2.5355\ \mu\text{m}$ ), where the low S/N values are related to the amount of energy initially entering the atmosphere should be used only with the realization that the data are mainly noise. This caveat is particularly directed towards future analyses where the goal would be to discern relatively small reflectance changes.

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\*Average S/N recorded for soy and wheat at  $2.4064\ \mu\text{m}$  =  $5.31 \pm 2.32$ .

Another potential for poor channel performance is identified by Potter and Eisenman (1962) who state that a PbS detector at ambient room temperature can be chopped, or modulated up to a frequency of 100 Hz without reducing the detectivity optimum. The Barnes reflectometer modulates at 400 Hz. Effects on the detectivity could be noticeable, and perhaps there are synergistic effects where the incoming signal is low. To our knowledge no work has been done with the instrument in this area.

## CONCLUSIONS AND RECOMMENDATIONS

This study analyzed the utility of the Barnes Field Spectral Reflectometer Model 14-758 using S/N as a measure of performance. The results indicate that 283 bands have a more than 95 percent chance of yielding a  $S/N \geq 8$  at least 90 percent of the time, leaving 90 bands with a  $S/N < 8$ . These 90 bands fall within the blue, red and far infrared regions of the spectrum. The performance in these poorer areas is principally related to the fact that the Barnes has only a PbS detector. This detector type is poor for observation in the visible region of the spectrum (for less than  $1.0 \mu\text{m}$ , photon counting silicon is over two orders of magnitude more sensitive than PbS) and accounts for the unsatisfactory performance in the blue and red regions. Also, the PbS detector does not compensate for the lessened solar flux in the mid IR. Another potential reason for poor performance is related to the design of the rotating filter wheel, specifically its two regions of overlap (red and far infrared). Atmospheric absorption peaks also contribute to the unreliability in various regions, particularly in the far infrared.

Since this experiment utilizes previously collected data, an experiment specifically designed to verify these results should be performed. Short of performing such an experiment, any program or investigation based upon Barnes reflectometer data in field crop observation should be adjusted so that when monitoring these 90 bands (or for investigations utilizing previously collected data) these unsatisfactory channels should be regarded circumspectly. Appendix B can be utilized to assess individual analytical usefulness. However, it is strongly felt that any results obtained or conclusions made using the tabulated, noisy, and highly variable bands as raw data would be questionable, particularly when the data are used to discern regions of small reflectance changes. We conclude by noting again that 283 channels are more than adequate to monitor vegetation, and that even omission of the 90 noted bands should not adversely affect future studies as there remains an over abundance of available information.



## ACKNOWLEDGMENTS

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# APPENDIX A

## TWO SIGMA CONFIDENCE LIMITS AROUND P FOR 373 CHANNELS (S/N < 8:1 = UNSATISFACTORY)

SOY-WHEAT				BAND	PROB	LOWER C.I.	UPPER C.I.
BAND	PROB	LOWER C.I.	UPPER C.I.	44	0.05	0.022	0.072
1	0.96	0.936	0.983	45	0.04	0.017	0.064
2	0.94	0.913	0.969	46	0.03	0.012	0.056
3	0.90	0.861	0.932	47	0.03	0.008	0.048
4	0.86	0.819	0.900	48	0.03	0.012	0.056
5	0.85	0.805	0.889	49	0.03	0.012	0.056
6	0.80	0.750	0.843	50	0.04	0.015	0.060
7	0.75	0.703	0.803	51	0.05	0.024	0.076
8	0.70	0.650	0.756	52	0.05	0.022	0.072
9	0.67	0.618	0.726	53	0.05	0.024	0.076
10	0.64	0.585	0.696	54	0.06	0.031	0.087
11	0.64	0.582	0.693	55	0.08	0.047	0.110
12	0.61	0.550	0.663	56	0.08	0.047	0.110
13	0.58	0.518	0.632	57	0.08	0.049	0.113
14	0.54	0.486	0.601	58	0.08	0.052	0.117
15	0.50	0.446	0.561	59	0.09	0.054	0.121
16	0.46	0.399	0.514	60	0.10	0.068	0.139
17	0.37	0.313	0.424	61	0.10	0.065	0.135
18	0.29	0.238	0.343	62	0.11	0.076	0.149
19	0.25	0.197	0.297	63	0.12	0.078	0.153
20	0.23	0.182	0.280	64	0.13	0.086	0.164
21	0.23	0.185	0.283	65	0.14	0.103	0.185
22	0.24	0.191	0.290	66	0.15	0.106	0.188
23	0.21	0.165	0.260	67	0.15	0.108	0.192
24	0.20	0.157	0.250	68	0.18	0.134	0.223
25	0.19	0.148	0.240	69	0.18	0.134	0.223
26	0.20	0.154	0.246	70	0.18	0.137	0.226
27	0.19	0.145	0.236	71	0.18	0.139	0.229
28	0.19	0.142	0.233	72	0.21	0.162	0.256
29	0.18	0.139	0.229	73	0.23	0.182	0.280
30	0.19	0.148	0.240	74	0.26	0.209	0.310
31	0.20	0.151	0.243	75	0.28	0.229	0.333
32	0.19	0.142	0.233	76	0.31	0.259	0.366
33	0.20	0.151	0.243	77	0.32	0.262	0.369
34	0.17	0.125	0.212	78	0.31	0.256	0.363
35	0.17	0.125	0.212	79	0.33	0.277	0.386
36	0.14	0.097	0.178	80	0.31	0.259	0.366
37	0.14	0.097	0.178	81	0.30	0.250	0.356
38	0.12	0.081	0.157	82	0.27	0.218	0.320
39	0.10	0.062	0.132	83	0.23	0.182	0.280
40	0.07	0.041	0.102	84	0.16	0.120	0.205
41	0.07	0.041	0.102	85	0.12	0.078	0.153
42	0.05	0.026	0.080	86	0.08	0.047	0.110
43	0.05	0.022	0.072	87	0.05	0.026	0.080
				88	0.03	0.008	0.048

BAND	PROB	LOWER C.I.	UPPER C.I.
89	0.03	0.006	0.044
90	0.02	0.002	0.036
91	0.02	0.000	0.031
92	0.53	0.474	0.589
93	0.44	0.383	0.498
94	0.37	0.316	0.428
95	0.29	0.235	0.340
96	0.16	0.117	0.202
97	0.14	0.103	0.185
98	0.12	0.084	0.160
99	0.10	0.062	0.132
100	0.08	0.044	0.106
101	0.06	0.034	0.091
102	0.04	0.019	0.068
103	0.02	0.004	0.040
104	0.02	0.004	0.040
105	0.01	-0.002	0.027
106	0.01	-0.002	0.027
107	0.01	-0.004	0.017
108	0.01	-0.003	0.022
109	0.01	-0.002	0.027
110	0.01	-0.002	0.027
111	0.01	-0.003	0.022
112	0.01	-0.003	0.022
113	0.01	-0.002	0.027
114	0.01	-0.004	0.017
115	0.01	-0.004	0.017
116	0.01	-0.004	0.017
117	0.01	-0.004	0.017
118	0.01	-0.002	0.027
119	0.01	-0.002	0.027
120	0.01	-0.002	0.027
121	0.01	-0.002	0.027
122	0.01	-0.002	0.027
123	0.01	-0.002	0.027
124	0.01	-0.003	0.022
125	0.01	-0.002	0.027
126	0.01	-0.003	0.022
127	0.01	-0.003	0.022
128	0.01	-0.003	0.022
129	0.01	-0.002	0.027
130	0.01	-0.002	0.027
131	0.01	-0.003	0.022
132	0.01	-0.002	0.027
133	0.01	-0.002	0.027
134	0.01	-0.002	0.027
135	0.01	-0.002	0.027
136	0.01	-0.002	0.027
137	0.01	-0.002	0.027
138	0.01	-0.002	0.027

BAND	PROB	LOWER C.I.	UPPER C.I.
139	0.01	-0.002	0.027
140	0.01	-0.002	0.027
141	0.01	-0.002	0.027
142	0.01	-0.003	0.022
143	0.01	-0.003	0.022
144	0.01	-0.004	0.017
145	0.01	-0.004	0.017
146	0.01	-0.003	0.022
147	0.01	-0.003	0.022
148	0.01	-0.004	0.017
149	0.01	-0.004	0.017
150	0.01	-0.004	0.017
151	0.01	-0.004	0.017
152	0.01	-0.004	0.017
153	0.01	-0.004	0.017
154	0.01	-0.004	0.017
155	0.01	-0.003	0.022
156	0.01	-0.003	0.022
157	0.01	-0.003	0.022
158	0.01	-0.003	0.022
159	0.01	-0.003	0.022
160	0.01	-0.004	0.017
161	0.01	-0.003	0.022
162	0.01	-0.002	0.027
163	0.02	0.000	0.031
164	0.02	0.000	0.031
165	0.02	0.002	0.036
166	0.02	0.004	0.040
167	0.04	0.015	0.060
168	0.02	0.004	0.040
169	0.02	0.000	0.031
170	0.02	0.000	0.031
171	0.01	-0.002	0.027
172	0.01	-0.002	0.027
173	0.01	-0.003	0.022
174	0.01	-0.004	0.017
175	0.01	-0.004	0.017
176	0.01	-0.004	0.017
177	0.01	-0.004	0.017
178	0.01	-0.004	0.017
179	0.01	-0.004	0.017
180	0.01	-0.004	0.017
181	0.01	-0.004	0.017
182	0.01	-0.004	0.017
183	0.01	-0.004	0.017
184	0.01	-0.004	0.017
185	0.01	-0.004	0.017
186	0.01	-0.004	0.017
187	0.01	-0.004	0.017
188	0.01	-0.004	0.017

BAND	PROB	LOWER C.I.	UPPER C.I.	BAND	PROB	LOWER C.I.	UPPER C.I.
189	0.01	-.004	0.017	239	0.01	-.003	0.022
190	0.01	-.004	0.017	240	0.01	-.003	0.022
191	0.01	-.004	0.017	241	0.01	-.003	0.022
192	0.01	-.004	0.017	242	0.01	-.003	0.022
193	0.01	-.004	0.017	243	0.01	-.003	0.022
194	0.01	-.004	0.017	244	0.01	-.003	0.022
195	0.01	-.004	0.017	245	0.01	-.003	0.022
196	0.00	-.005	0.011	246	0.01	-.003	0.022
197	0.00	-.005	0.011	247	0.01	-.003	0.022
198	0.00	-.005	0.011	248	0.01	-.003	0.022
199	0.00	-.005	0.011	249	0.01	-.003	0.022
200	0.00	-.005	0.011	250	0.01	-.003	0.022
201	0.00	-.005	0.011	251	0.01	-.003	0.022
202	0.00	-.005	0.011	252	0.01	-.003	0.022
203	0.00	-.005	0.011	253	0.01	-.003	0.022
204	0.00	-.005	0.011	254	0.01	-.003	0.022
205	0.00	-.005	0.011	255	0.01	-.003	0.022
206	0.00	-.005	0.011	256	0.01	-.003	0.022
207	0.00	-.005	0.011	257	0.01	-.003	0.022
208	0.00	-.005	0.011	258	0.01	-.003	0.022
209	0.00	-.005	0.011	259	0.01	-.003	0.022
210	0.00	-.005	0.011	260	0.01	-.003	0.022
211	0.01	-.004	0.017	261	0.01	-.003	0.022
212	0.01	-.003	0.022	262	0.01	-.003	0.022
213	0.02	0.002	0.036	263	0.01	-.003	0.022
214	0.04	0.017	0.064	264	0.01	-.002	0.027
215	0.05	0.026	0.080	265	0.01	-.002	0.027
216	0.05	0.026	0.080	266	0.02	0.002	0.036
217	0.04	0.017	0.064	267	0.02	0.004	0.040
218	0.02	0.004	0.040	268	0.04	0.017	0.064
219	0.02	0.002	0.036	269	0.10	0.062	0.132
220	0.01	-.002	0.027	270	0.14	0.097	0.178
221	0.01	-.003	0.022	271	0.20	0.157	0.250
222	0.01	-.003	0.022	272	0.45	0.396	0.510
223	0.01	-.004	0.017	273	0.70	0.644	0.750
224	0.01	-.004	0.017	274	0.88	0.847	0.922
225	0.01	-.004	0.017	275	0.98	0.969	1.000
226	0.01	-.003	0.022	276	1.00	0.989	1.005
227	0.01	-.003	0.022	277	1.00	0.989	1.005
228	0.01	-.003	0.022	278	1.00	0.989	1.005
229	0.01	-.003	0.022	279	1.00	0.989	1.005
230	0.01	-.003	0.022	280	1.00	0.989	1.005
231	0.01	-.003	0.022	281	0.99	0.973	1.002
232	0.01	-.003	0.022	282	0.97	0.952	0.992
233	0.01	-.003	0.022	283	0.93	0.901	0.961
234	0.01	-.003	0.022	284	0.73	0.680	0.782
235	0.01	-.003	0.022	285	0.53	0.471	0.586
236	0.01	-.003	0.022	286	0.33	0.274	0.382
237	0.01	-.003	0.022	287	0.13	0.092	0.171
238	0.01	-.003	0.022	288	0.09	0.060	0.128

BAND	PROB	LOWER C.I.	UPPER C.I.
289	0.03	0.010	0.052
290	0.02	0.000	0.031
291	0.02	0.000	0.031
292	0.01	-.002	0.027
293	0.03	0.012	0.056
294	0.01	-.003	0.022
295	0.01	-.004	0.017
296	0.01	-.004	0.017
297	0.01	-.004	0.017
298	0.01	-.004	0.017
299	0.01	-.004	0.017
300	0.01	-.004	0.017
301	0.01	-.004	0.017
302	0.01	-.004	0.017
303	0.01	-.004	0.017
304	0.01	-.004	0.017
305	0.01	-.004	0.017
306	0.01	-.004	0.017
307	0.02	0.002	0.036
308	0.02	0.002	0.036
309	0.02	0.002	0.036
310	0.02	0.002	0.036
311	0.02	0.002	0.036
312	0.02	0.002	0.036
313	0.02	0.002	0.036
314	0.02	0.002	0.036
315	0.03	0.010	0.052
316	0.08	0.052	0.117
317	0.22	0.168	0.263
318	0.69	0.637	0.744
319	0.98	0.960	0.996
320	1.00	0.989	1.005
321	1.00	0.989	1.005
322	1.00	0.989	1.005
323	1.00	0.989	1.005
324	0.90	0.861	0.932
325	0.80	0.750	0.843
326	0.59	0.537	0.650
327	0.37	0.313	0.424
328	0.16	0.117	0.202
329	0.10	0.065	0.135
330	0.08	0.047	0.110
331	0.07	0.041	0.102
332	0.04	0.019	0.068
333	0.04	0.015	0.060
334	0.04	0.017	0.064
335	0.04	0.017	0.064
336	0.04	0.015	0.060
337	0.03	0.012	0.056
338	0.03	0.010	0.052

BAND	PROB	LOWER C.I.	UPPER C.I.
339	0.03	0.010	0.052
340	0.03	0.010	0.052
341	0.03	0.010	0.052
342	0.03	0.010	0.052
343	0.03	0.010	0.052
344	0.04	0.015	0.060
345	0.04	0.015	0.060
346	0.04	0.019	0.068
347	0.07	0.036	0.095
348	0.08	0.049	0.113
349	0.09	0.054	0.121
350	0.09	0.057	0.124
351	0.09	0.057	0.124
352	0.11	0.070	0.142
353	0.09	0.060	0.128
354	0.10	0.065	0.135
355	0.10	0.068	0.139
356	0.12	0.081	0.157
357	0.14	0.100	0.181
358	0.15	0.108	0.192
359	0.17	0.125	0.212
360	0.20	0.154	0.246
361	0.23	0.182	0.280
362	0.32	0.268	0.376
363	0.43	0.371	0.485
364	0.60	0.547	0.659
365	0.74	0.690	0.791
366	0.89	0.851	0.924
367	0.99	0.983	1.004
368	1.00	0.989	1.005
369	1.00	0.989	1.005
370	1.00	0.989	1.005
371	1.00	0.989	1.005
372	1.00	0.989	1.005
373	1.00	0.989	1.005

CORN			
BAND	PROB	LOWER C.I.	UPPER C.I.
1	0.93	0.888	0.975
2	0.90	0.849	0.951
3	0.89	0.834	0.941
4	0.86	0.797	0.915
5	0.83	0.769	0.894
6	0.82	0.755	0.883
7	0.80	0.733	0.867
8	0.79	0.726	0.861
9	0.77	0.699	0.839
10	0.76	0.685	0.827

BAND	PROB	LOWER C.I.	UPPER C.I.	BAND	PROB	LOWER C.I.	UPPER C.I.
11	0.74	0.671	0.816	60	0.10	0.049	0.151
12	0.73	0.658	0.805	61	0.11	0.054	0.158
13	0.68	0.598	0.752	62	0.11	0.054	0.158
14	0.58	0.500	0.663	63	0.11	0.059	0.166
15	0.53	0.443	0.607	64	0.12	0.064	0.173
16	0.43	0.350	0.513	65	0.12	0.064	0.173
17	0.34	0.259	0.416	66	0.13	0.069	0.181
18	0.30	0.224	0.376	67	0.12	0.064	0.173
19	0.28	0.207	0.356	68	0.14	0.085	0.203
20	0.23	0.161	0.301	69	0.13	0.069	0.181
21	0.26	0.190	0.335	70	0.14	0.080	0.195
22	0.26	0.190	0.335	71	0.14	0.085	0.203
23	0.23	0.156	0.294	72	0.16	0.096	0.217
24	0.24	0.167	0.308	73	0.18	0.112	0.238
25	0.22	0.150	0.287	74	0.19	0.128	0.260
26	0.22	0.150	0.287	75	0.20	0.133	0.267
27	0.24	0.167	0.308	76	0.20	0.133	0.267
28	0.16	0.101	0.224	77	0.18	0.117	0.245
29	0.22	0.150	0.287	78	0.18	0.117	0.245
30	0.21	0.144	0.281	79	0.17	0.106	0.231
31	0.20	0.133	0.267	80	0.16	0.096	0.217
32	0.16	0.101	0.224	81	0.16	0.096	0.217
33	0.16	0.096	0.217	82	0.19	0.128	0.260
34	0.16	0.101	0.224	83	0.21	0.144	0.281
35	0.16	0.096	0.217	84	0.14	0.080	0.195
36	0.16	0.096	0.217	85	0.13	0.075	0.188
37	0.13	0.075	0.188	86	0.10	0.049	0.151
38	0.13	0.069	0.181	87	0.09	0.040	0.135
39	0.11	0.059	0.166	88	0.08	0.035	0.128
40	0.11	0.054	0.158	89	0.06	0.021	0.104
41	0.09	0.040	0.135	90	0.07	0.025	0.112
42	0.08	0.030	0.120	91	0.06	0.017	0.096
43	0.07	0.025	0.112	92	0.53	0.449	0.614
44	0.06	0.021	0.104	93	0.31	0.236	0.389
45	0.07	0.025	0.112	94	0.24	0.167	0.308
46	0.06	0.017	0.096	95	0.16	0.096	0.217
47	0.07	0.025	0.112	96	0.14	0.080	0.195
48	0.06	0.021	0.104	97	0.13	0.069	0.181
49	0.07	0.025	0.112	98	0.11	0.054	0.158
50	0.06	0.017	0.096	99	0.10	0.049	0.151
51	0.05	0.012	0.088	100	0.11	0.054	0.158
52	0.05	0.012	0.088	101	0.09	0.044	0.143
53	0.07	0.025	0.112	102	0.08	0.030	0.120
54	0.07	0.025	0.112	103	0.07	0.025	0.112
55	0.08	0.030	0.120	104	0.07	0.025	0.112
56	0.08	0.035	0.128	105	0.06	0.021	0.104
57	0.10	0.049	0.151	106	0.06	0.017	0.096
58	0.11	0.054	0.158	107	0.05	0.012	0.088
59	0.12	0.064	0.173	108	0.05	0.012	0.088

BAND	PROB	LOWER C.I.	UPPER C.I.	BAND	PROB	LOWER C.I.	UPPER C.I.
109	0.05	0.012	0.088	158	0.13	0.069	0.181
110	0.04	0.008	0.079	159	0.13	0.069	0.181
111	0.04	0.008	0.079	160	0.13	0.069	0.181
112	0.04	0.008	0.079	161	0.13	0.069	0.181
113	0.05	0.012	0.088	162	0.13	0.069	0.181
114	0.07	0.025	0.112	163	0.12	0.064	0.173
115	0.11	0.054	0.158	164	0.13	0.075	0.188
116	0.13	0.069	0.181	165	0.13	0.075	0.188
117	0.13	0.069	0.181	166	0.13	0.075	0.188
118	0.13	0.069	0.181	167	0.13	0.075	0.188
119	0.13	0.069	0.181	168	0.13	0.075	0.188
120	0.13	0.069	0.181	169	0.13	0.075	0.188
121	0.13	0.069	0.181	170	0.13	0.075	0.188
122	0.13	0.069	0.181	171	0.13	0.069	0.181
123	0.13	0.069	0.181	172	0.13	0.069	0.181
124	0.13	0.069	0.181	173	0.13	0.069	0.181
125	0.13	0.069	0.181	174	0.13	0.069	0.181
126	0.13	0.069	0.181	175	0.13	0.069	0.181
127	0.13	0.069	0.181	176	0.12	0.064	0.173
128	0.13	0.069	0.181	177	0.11	0.059	0.166
129	0.13	0.069	0.181	178	0.09	0.044	0.143
130	0.13	0.069	0.181	179	0.09	0.044	0.143
131	0.13	0.069	0.181	180	0.09	0.044	0.143
132	0.13	0.069	0.181	181	0.09	0.040	0.135
133	0.13	0.069	0.181	182	0.09	0.040	0.135
134	0.13	0.069	0.181	183	0.09	0.040	0.135
135	0.13	0.069	0.181	184	0.09	0.040	0.135
136	0.13	0.069	0.181	185	0.08	0.035	0.128
137	0.13	0.069	0.181	186	0.10	0.049	0.151
138	0.13	0.069	0.181	187	0.09	0.044	0.143
139	0.13	0.069	0.181	188	0.09	0.040	0.135
140	0.13	0.069	0.181	189	0.09	0.040	0.135
141	0.13	0.069	0.181	190	0.09	0.040	0.135
142	0.13	0.069	0.181	191	0.09	0.040	0.135
143	0.13	0.069	0.181	192	0.09	0.044	0.143
144	0.13	0.069	0.181	193	0.09	0.044	0.143
145	0.13	0.069	0.181	194	0.09	0.044	0.143
146	0.13	0.069	0.181	195	0.09	0.044	0.143
147	0.13	0.069	0.181	196	0.09	0.044	0.143
148	0.13	0.069	0.181	197	0.09	0.044	0.143
149	0.13	0.075	0.188	198	0.09	0.044	0.143
150	0.13	0.069	0.181	199	0.09	0.044	0.143
151	0.13	0.069	0.181	200	0.09	0.044	0.143
152	0.13	0.069	0.181	201	0.09	0.040	0.135
153	0.13	0.069	0.181	202	0.09	0.044	0.143
154	0.13	0.069	0.181	203	0.09	0.040	0.135
155	0.13	0.069	0.181	204	0.09	0.040	0.135
156	0.13	0.069	0.181	205	0.09	0.044	0.143
157	0.13	0.069	0.181	206	0.09	0.040	0.135



BAND	PROB	LOWER C.I.	UPPER C.I.	BAND	PROB	LOWER C.I.	UPPER C.I.
207	0.11	0.059	0.166	256	0.04	0.008	0.079
208	0.12	0.064	0.173	257	0.06	0.017	0.096
209	0.12	0.064	0.173	258	0.04	0.004	0.071
210	0.13	0.075	0.188	259	0.04	0.008	0.079
211	0.14	0.080	0.195	260	0.03	0.001	0.062
212	0.14	0.085	0.203	261	0.03	0.001	0.062
213	0.15	0.090	0.210	262	0.03	0.001	0.062
214	0.16	0.096	0.217	263	0.04	0.004	0.071
215	0.18	0.117	0.245	264	0.09	0.040	0.135
216	0.18	0.112	0.238	265	0.13	0.075	0.188
217	0.15	0.090	0.210	266	0.14	0.085	0.203
218	0.12	0.064	0.173	267	0.16	0.101	0.224
219	0.09	0.040	0.135	268	0.14	0.085	0.203
220	0.09	0.044	0.143	269	0.20	0.133	0.267
221	0.09	0.040	0.135	270	0.26	0.190	0.335
222	0.08	0.035	0.128	271	0.33	0.248	0.402
223	0.08	0.030	0.120	272	0.49	0.405	0.570
224	0.06	0.021	0.104	273	0.86	0.805	0.920
225	0.06	0.017	0.096	274	0.89	0.842	0.946
226	0.06	0.017	0.096	275	0.92	0.872	0.965
227	0.06	0.017	0.096	276	0.91	0.857	0.956
228	0.05	0.012	0.088	277	0.88	0.827	0.936
229	0.04	0.004	0.071	278	0.87	0.812	0.925
230	0.04	0.004	0.071	279	0.86	0.805	0.920
231	0.04	0.004	0.071	280	0.87	0.812	0.925
232	0.04	0.004	0.071	281	0.86	0.805	0.920
233	0.03	-0.003	0.053	282	0.85	0.790	0.910
234	0.04	0.004	0.071	283	0.84	0.783	0.904
235	0.04	0.008	0.079	284	0.78	0.713	0.850
236	0.04	0.008	0.079	285	0.61	0.526	0.687
237	0.03	0.001	0.062	286	0.43	0.350	0.513
238	0.03	-0.003	0.053	287	0.29	0.213	0.362
239	0.04	0.004	0.071	288	0.23	0.161	0.301
240	0.04	0.008	0.079	289	0.18	0.117	0.245
241	0.04	0.004	0.071	290	0.09	0.040	0.135
242	0.04	0.008	0.079	291	0.06	0.021	0.104
243	0.04	0.008	0.079	292	0.05	0.012	0.088
244	0.05	0.012	0.088	293	0.03	0.001	0.062
245	0.06	0.017	0.096	294	0.03	0.001	0.062
246	0.05	0.012	0.088	295	0.04	0.008	0.079
247	0.04	0.004	0.071	296	0.04	0.004	0.071
248	0.04	0.008	0.079	297	0.04	0.004	0.071
249	0.04	0.008	0.079	298	0.03	0.001	0.062
250	0.03	-0.003	0.053	299	0.03	0.001	0.062
251	0.03	-0.003	0.053	300	0.05	0.012	0.088
252	0.04	0.004	0.071	301	0.05	0.012	0.088
253	0.02	-0.006	0.043	302	0.06	0.017	0.096
254	0.03	0.001	0.062	303	0.06	0.021	0.104
255	0.04	0.008	0.079	304	0.06	0.021	0.104

BAND	PROB	LOWER C.I.	UPPER C.I.	BAND	PROB	LOWER C.I.	UPPER C.I.
305	0.06	0.021	0.104	354	0.22	0.150	0.287
306	0.06	0.021	0.104	355	0.21	0.144	0.281
307	0.07	0.025	0.112	356	0.25	0.178	0.322
308	0.06	0.021	0.104	357	0.26	0.190	0.335
309	0.09	0.044	0.143	358	0.29	0.213	0.362
310	0.12	0.064	0.173	359	0.31	0.236	0.389
311	0.12	0.064	0.173	360	0.34	0.259	0.416
312	0.13	0.069	0.181	361	0.34	0.265	0.422
313	0.13	0.069	0.181	362	0.38	0.295	0.455
314	0.14	0.080	0.195	363	0.50	0.418	0.582
315	0.16	0.101	0.224	364	0.64	0.565	0.723
316	0.28	0.201	0.349	365	0.88	0.819	0.931
317	0.50	0.418	0.582	366	0.95	0.912	0.988
318	0.81	0.747	0.878	367	0.97	0.938	0.999
319	0.89	0.834	0.941	368	0.99	0.967	1.008
320	0.89	0.834	0.941	369	0.99	0.967	1.008
321	0.89	0.834	0.941	370	0.99	0.967	1.008
322	0.88	0.827	0.936	371	0.99	0.978	1.009
323	0.86	0.797	0.915	372	0.99	0.978	1.009
324	0.83	0.769	0.894	373	1.00	0.997	1.003
325	0.70	0.624	0.776				
326	0.62	0.539	0.699				
327	0.39	0.313	0.474				
328	0.24	0.173	0.315				
329	0.23	0.161	0.301				
330	0.21	0.144	0.281				
331	0.19	0.122	0.253				
332	0.17	0.106	0.231				
333	0.13	0.075	0.188				
334	0.13	0.069	0.181				
335	0.11	0.054	0.158				
336	0.10	0.049	0.151				
337	0.09	0.040	0.135				
338	0.09	0.040	0.135				
339	0.09	0.040	0.135				
340	0.09	0.040	0.135				
341	0.08	0.035	0.128				
342	0.09	0.040	0.135				
343	0.09	0.040	0.135				
344	0.09	0.040	0.135				
345	0.11	0.059	0.166				
346	0.19	0.122	0.253				
347	0.23	0.161	0.301				
348	0.21	0.144	0.281				
349	0.22	0.150	0.287				
350	0.23	0.161	0.301				
351	0.26	0.184	0.329				
352	0.26	0.184	0.329				
353	0.26	0.184	0.329				

# APPENDIX B

## MEAN AND STANDARD DEVIATION OF S/N FOR EACH CHANNEL RECORDED AS A POWER OF 2.0

SOY-WHEAT			BAND	AVERAGE	STANDARD DEVIATION
BAND	AVERAGE	STANDARD DEVIATION	44	3.92	1.06
1	0.76	0.96	45	3.97	1.05
2	0.99	1.00	46	4.03	1.02
3	1.16	1.08	47	4.06	1.01
4	1.45	1.07	48	4.07	1.02
5	1.58	1.06	49	4.06	1.03
6	1.82	1.05	50	4.05	1.03
7	1.95	1.06	51	4.03	1.05
8	2.16	1.08	52	3.99	1.08
9	2.22	1.10	53	3.97	1.10
10	2.35	1.05	54	3.95	1.12
11	2.37	1.08	55	3.90	1.13
12	2.44	1.04	56	3.84	1.14
13	2.47	1.07	57	3.82	1.16
14	2.55	1.03	58	3.78	1.18
15	2.63	1.07	59	3.76	1.17
16	2.72	1.10	60	3.73	1.20
17	2.87	1.10	61	3.75	1.19
18	3.00	1.07	62	3.74	1.22
19	3.08	1.08	63	3.72	1.24
20	3.12	1.10	64	3.69	1.23
21	3.16	1.13	65	3.64	1.27
22	3.14	1.14	66	3.61	1.26
23	3.17	1.14	67	3.59	1.27
24	3.21	1.12	68	3.55	1.27
25	3.23	1.12	69	3.54	1.30
26	3.22	1.14	70	3.53	1.28
27	3.26	1.14	71	3.52	1.31
28	3.25	1.12	72	3.47	1.34
29	3.26	1.14	73	3.45	1.35
30	3.26	1.14	74	3.42	1.38
31	3.23	1.14	75	3.38	1.36
32	3.26	1.14	76	3.35	1.41
33	3.27	1.15	77	3.36	1.40
34	3.32	1.14	78	3.35	1.44
35	3.33	1.15	79	3.36	1.47
36	3.38	1.12	80	3.42	1.47
37	3.41	1.15	81	3.42	1.46
38	3.47	1.11	82	3.48	1.44
39	3.51	1.10	83	3.51	1.41
40	3.62	1.07	84	3.63	1.32
41	3.71	1.07	85	3.74	1.28
42	3.85	1.06	86	3.93	1.21
43	3.88	1.05	87	4.07	1.12
			88	4.33	1.02

ORIGINAL PAGE IS  
OF POOR QUALITY

BAND	AVERAGE	STANDARD DEVIATION	BAND	AVERAGE	STANDARD DEVIATION
89	4.51	1.02	139	5.43	0.97
90	4.63	0.98	140	5.49	0.95
91	4.75	0.91	141	5.51	0.94
92	2.55	1.44	142	5.53	0.90
93	2.95	1.39	143	5.56	0.89
94	3.25	1.42	144	5.57	0.88
95	3.49	1.45	145	5.60	0.87
96	3.68	1.36	146	5.61	0.89
97	3.76	1.36	147	5.62	0.88
98	3.84	1.35	148	5.65	0.87
99	3.90	1.34	149	5.67	0.90
100	3.97	1.31	150	5.73	0.93
101	4.13	1.21	151	5.72	0.93
102	4.27	1.14	152	5.72	0.95
103	4.53	1.01	153	5.70	0.95
104	4.69	0.99	154	5.68	0.94
105	4.88	0.93	155	5.63	0.93
106	5.02	0.88	156	5.57	0.95
107	5.17	0.93	157	5.54	0.97
108	5.24	0.96	158	5.53	1.01
109	5.32	0.96	159	5.54	1.04
110	5.35	0.97	160	5.51	1.02
111	5.43	0.94	161	5.43	0.97
112	5.44	0.93	162	5.41	1.02
113	5.48	0.92	163	5.21	1.07
114	5.52	0.89	164	5.01	1.10
115	5.52	0.90	165	4.89	1.14
116	5.50	0.89	166	4.77	1.14
117	5.47	0.92	167	4.77	1.18
118	5.38	0.98	168	4.83	1.16
119	5.33	1.00	169	4.98	1.15
120	5.32	1.00	170	5.04	1.11
121	5.37	0.98	171	5.26	1.07
122	5.44	0.97	172	5.49	1.14
123	5.50	0.92	173	5.68	1.08
124	5.50	0.93	174	5.81	1.07
125	5.50	0.93	175	5.93	1.07
126	5.50	0.93	176	6.08	1.04
127	5.50	0.93	177	6.16	1.07
128	5.50	0.92	178	6.23	1.03
129	5.47	0.96	179	6.30	1.01
130	5.45	0.96	180	6.36	1.01
131	5.45	0.96	181	6.38	1.00
132	5.38	1.00	182	6.38	1.02
133	5.34	1.00	183	6.41	1.02
134	5.32	0.99	184	6.42	1.00
135	5.35	1.00	185	6.42	1.02
136	5.36	1.00	186	6.43	1.01
137	5.33	1.01	187	6.42	1.02
138	5.38	1.03	188	6.44	1.00

BAND	AVERAGE	STANDARD DEVIATION
189	6.44	1.00
190	6.44	0.99
191	6.47	0.99
192	6.47	0.99
193	6.47	1.00
194	6.47	0.97
195	6.48	0.97
196	6.51	0.92
197	6.49	0.93
198	6.47	0.93
199	6.48	0.91
200	6.49	0.94
201	6.48	0.94
202	6.48	0.93
203	6.45	0.97
204	6.43	0.99
205	6.46	0.95
206	6.38	0.97
207	6.32	0.98
208	6.20	1.03
209	6.00	1.06
210	5.88	1.05
211	5.63	1.11
212	5.37	1.15
213	5.00	1.15
214	4.86	1.23
215	4.69	1.26
216	4.71	1.27
217	4.92	1.29
218	5.10	1.26
219	5.33	1.25
220	5.62	1.19
221	5.86	1.17
222	5.99	1.14
223	6.13	1.07
224	6.22	1.08
225	6.29	1.07
226	6.31	1.10
227	6.34	1.10
228	6.36	1.08
229	6.39	1.11
230	6.42	1.12
231	6.43	1.10
232	6.47	1.08
233	6.50	1.06
234	6.48	1.07
235	6.50	1.08
236	6.55	1.07
237	6.59	1.06
238	6.59	1.11

BAND	AVERAGE	STANDARD DEVIATION
239	6.61	1.12
240	6.64	1.10
241	6.68	1.09
242	6.70	1.11
243	6.69	1.09
244	6.67	1.09
245	6.63	1.08
246	6.58	1.07
247	6.57	1.06
248	6.55	1.09
249	6.57	1.08
250	6.58	1.09
251	6.59	1.09
252	6.63	1.11
253	6.68	1.13
254	6.69	1.13
255	6.63	1.13
256	6.62	1.12
257	6.58	1.10
258	6.53	1.12
259	6.45	1.14
260	6.41	1.15
261	6.31	1.15
262	6.19	1.15
263	6.02	1.21
264	5.89	1.24
265	5.71	1.25
266	5.48	1.23
267	5.08	1.19
268	4.86	1.25
269	4.33	1.26
270	3.86	1.24
271	3.13	1.28
272	2.52	1.22
273	1.88	1.16
274	1.37	1.06
275	0.88	0.98
276	0.59	0.90
277	0.42	0.83
278	0.39	0.83
279	0.38	0.82
280	0.45	0.87
281	0.52	0.93
282	0.68	1.02
283	0.81	1.12
284	1.53	1.39
285	2.26	1.51
286	3.15	1.52
287	3.89	1.46
288	4.43	1.40

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BAND	AVERAGE	STANDARD DEVIATION
289	5.01	1.35
290	5.58	1.28
291	6.14	1.26
292	6.64	1.19
293	6.82	1.69
294	7.31	1.23
295	7.43	1.18
296	7.51	1.15
297	7.53	1.15
298	7.58	1.17
299	7.63	1.20
300	7.73	1.21
301	7.80	1.20
302	7.84	1.18
303	7.84	1.19
304	7.84	1.17
305	7.83	1.21
306	7.78	1.21
307	7.66	1.46
308	7.58	1.47
309	7.46	1.46
310	7.29	1.42
311	7.17	1.45
312	7.02	1.46
313	6.77	1.45
314	6.25	1.36
315	5.63	1.39
316	4.53	1.37
317	3.21	1.36
318	1.84	1.25
319	0.86	1.03
320	0.38	0.79
321	0.24	0.78
322	0.30	0.83
323	0.41	0.91
324	0.80	1.20
325	1.38	1.46
326	2.28	1.56
327	3.09	1.61
328	3.88	1.64
329	4.27	1.59
330	4.49	1.59
331	4.59	1.57
332	4.86	1.52
333	5.10	1.53
334	5.34	1.55
335	5.42	1.52
336	5.49	1.49
337	5.58	1.48
338	5.69	1.44

BAND	AVERAGE	STANDARD DEVIATION
339	5.77	1.47
340	5.77	1.45
341	5.81	1.44
342	5.75	1.45
343	5.58	1.43
344	5.32	1.33
345	5.15	1.36
346	4.91	1.35
347	4.43	1.23
348	4.17	1.22
349	4.13	1.26
350	4.10	1.27
351	4.11	1.25
352	4.11	1.31
353	4.10	1.28
354	4.07	1.28
355	4.05	1.28
356	3.99	1.31
357	3.79	1.30
358	3.59	1.25
359	3.38	1.19
360	3.13	1.21
361	2.97	1.24
362	2.70	1.26
363	2.41	1.22
364	2.05	1.15
365	1.78	1.15
366	1.37	1.10
367	1.00	0.96
368	0.53	0.82
369	0.23	0.66
370	0.05	0.52
371	0.03	0.50
372	0.03	0.50
373	0.03	0.50

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BAND	AVERAGE	STANDARD DEVIATION
1	0.71	0.96
2	0.90	1.04
3	1.04	1.06
4	1.23	1.15
5	1.43	1.17
6	1.57	1.19
7	1.70	1.27
8	1.79	1.30
9	1.90	1.31
10	2.19	1.19

BAND	AVERAGE	STANDARD DEVIATION
11	2.27	1.23
12	2.26	1.21
13	2.40	1.24
14	2.47	1.27
15	2.56	1.24
16	2.65	1.25
17	2.82	1.25
18	2.91	1.25
19	3.03	1.25
20	3.09	1.24
21	3.11	1.24
22	3.14	1.28
23	3.15	1.25
24	3.14	1.27
25	3.15	1.27
26	3.20	1.27
27	3.16	1.28
28	3.24	1.20
29	3.19	1.25
30	3.20	1.27
31	3.24	1.23
32	3.29	1.26
33	3.32	1.28
34	3.31	1.27
35	3.33	1.29
36	3.37	1.28
37	3.46	1.29
38	3.49	1.30
39	3.52	1.29
40	3.57	1.28
41	3.72	1.25
42	3.82	1.22
43	3.89	1.24
44	3.95	1.22
45	3.98	1.23
46	4.02	1.21
47	3.99	1.25
48	4.05	1.23
49	4.04	1.25
50	4.04	1.25
51	4.05	1.22
52	4.00	1.23
53	3.94	1.26
54	3.91	1.26
55	3.88	1.30
56	3.83	1.30
57	3.77	1.34
58	3.71	1.33
59	3.69	1.33
60	3.72	1.32

BAND	AVERAGE	STANDARD DEVIATION
61	3.71	1.31
62	3.67	1.32
63	3.67	1.36
64	3.63	1.36
65	3.63	1.35
66	3.60	1.35
67	3.63	1.36
68	3.59	1.36
69	3.59	1.36
70	3.59	1.38
71	3.59	1.40
72	3.54	1.41
73	3.57	1.43
74	3.46	1.37
75	3.45	1.38
76	3.52	1.40
77	3.52	1.42
78	3.52	1.38
79	3.55	1.41
80	3.56	1.36
81	3.57	1.37
82	3.54	1.42
83	3.49	1.45
84	3.61	1.38
85	3.67	1.35
86	3.84	1.35
87	3.97	1.36
88	4.13	1.32
89	4.20	1.29
90	4.33	1.27
91	4.45	1.28
92	2.77	1.49
93	3.16	1.45
94	3.42	1.45
95	3.60	1.43
96	3.71	1.48
97	3.83	1.51
98	3.87	1.47
99	3.94	1.47
100	3.97	1.45
101	4.12	1.43
102	4.26	1.40
103	4.32	1.37
104	4.44	1.35
105	4.63	1.25
106	4.73	1.31
107	4.88	1.20
108	4.93	1.17
109	5.02	1.14
110	5.14	1.11

BAND	AVERAGE	STANDARD DEVIATION
111	5.45	1.07
112	5.47	1.10
113	5.52	1.02
114	5.52	0.98
115	5.56	1.03
116	5.55	1.04
117	5.53	1.03
118	5.44	1.03
119	5.35	1.06
120	5.42	1.01
121	5.48	1.01
122	5.52	1.01
123	5.59	0.96
124	5.57	0.96
125	5.59	0.94
126	5.56	0.99
127	5.59	0.95
128	5.55	0.98
129	5.55	0.95
130	5.53	0.99
131	5.51	1.04
132	5.47	0.97
133	5.34	1.02
134	5.28	1.00
135	5.24	1.08
136	5.32	1.02
137	5.47	1.01
138	5.52	1.00
139	5.58	0.96
140	5.61	0.95
141	5.61	1.00
142	5.61	0.91
143	5.63	0.92
144	5.62	0.93
145	5.66	0.93
146	5.66	0.95
147	5.67	0.97
148	5.71	0.98
149	5.71	1.09
150	5.77	1.02
151	5.77	0.98
152	5.73	1.02
153	5.74	1.01
154	5.64	0.98
155	5.64	0.98
156	5.59	1.00
157	5.59	1.03
158	5.60	0.98
159	5.61	1.02
160	5.58	1.03

BAND	AVERAGE	STANDARD DEVIATION
161	5.41	1.07
162	5.31	1.06
163	5.08	1.15
164	4.94	1.22
165	4.61	1.21
166	4.57	1.23
167	4.61	1.22
168	4.74	1.27
169	4.97	1.25
170	5.11	1.20
171	5.29	1.14
172	5.52	1.13
173	5.71	1.04
174	5.82	1.07
175	6.04	1.09
176	6.06	1.07
177	6.17	1.00
178	6.31	0.99
179	6.39	1.01
180	6.47	0.98
181	6.46	1.08
182	6.53	0.97
183	6.56	0.96
184	6.56	0.96
185	6.55	0.94
186	6.54	1.00
187	6.58	0.98
188	6.56	0.95
189	6.54	0.97
190	6.56	0.95
191	6.52	0.96
192	6.51	1.00
193	6.54	1.00
194	6.54	0.99
195	6.52	0.97
196	6.51	1.01
197	6.52	1.05
198	6.47	1.07
199	6.52	1.06
200	6.51	1.04
201	6.49	1.01
202	6.42	1.05
203	6.45	1.04
204	6.40	1.06
205	6.36	1.06
206	6.31	1.06
207	6.09	1.15
208	5.96	1.18
209	5.84	1.14
210	5.66	1.18



BAND	AVERAGE	STANDARD DEVIATION
211	5.36	1.28
212	5.10	1.32
213	4.85	1.44
214	4.54	1.45
215	4.50	1.53
216	4.51	1.50
217	4.79	1.50
218	5.08	1.38
219	5.29	1.32
220	5.59	1.26
221	5.84	1.23
222	5.94	1.21
223	6.07	1.17
224	6.07	1.15
225	6.20	1.17
226	6.30	1.21
227	6.34	1.19
228	6.36	1.16
229	6.42	1.16
230	6.46	1.08
231	6.49	1.07
232	6.55	1.06
233	6.54	1.02
234	6.60	1.06
235	6.51	1.14
236	6.58	1.07
237	6.63	1.10
238	6.69	1.11
239	6.74	1.11
240	6.76	1.06
241	6.81	0.98
242	6.81	1.03
243	6.82	1.05
244	6.77	1.18
245	6.77	1.13
246	6.72	1.05
247	6.71	1.07
248	6.72	1.05
249	6.73	1.05
250	6.72	1.04
251	6.73	1.10
252	6.69	1.12
253	6.61	1.17
254	6.57	1.24
255	6.49	1.31
256	6.39	1.46
257	6.27	1.48
258	6.18	1.60
259	6.14	1.63
260	6.09	1.64

BAND	AVERAGE	STANDARD DEVIATION
261	5.89	1.62
262	5.69	1.54
263	5.53	1.59
264	5.35	1.70
265	5.05	1.73
266	4.84	1.77
267	4.52	1.69
268	4.19	1.71
269	3.84	1.68
270	3.29	1.57
271	2.75	1.55
272	2.34	1.51
273	1.71	1.53
274	1.44	1.63
275	1.09	1.67
276	0.94	1.77
277	0.87	1.92
278	0.91	2.06
279	0.91	2.08
280	0.97	2.13
281	1.10	2.15
282	1.26	2.25
283	1.37	2.32
284	1.85	2.37
285	2.36	2.38
286	3.09	2.38
287	3.73	2.36
288	4.22	2.22
289	4.81	2.14
290	5.41	1.95
291	5.93	1.82
292	6.36	1.80
293	6.74	1.76
294	6.76	1.76
295	6.98	1.81
296	7.12	1.79
297	7.19	1.85
298	7.17	1.97
299	7.23	2.06
300	7.21	2.16
301	7.16	2.20
302	7.13	2.26
303	7.10	2.28
304	7.06	2.30
305	6.98	2.30
306	6.99	2.29
307	6.86	2.35
308	6.80	2.41
309	6.66	2.49
310	6.32	2.62

BAND	AVERAGE	STANDARD DEVIATION
311	6.13	2.57
312	5.90	2.49
313	5.67	2.42
314	5.13	2.22
315	4.48	1.96
316	3.36	1.75
317	2.32	1.60
318	1.48	1.57
319	0.90	1.53
320	0.75	1.70
321	0.72	1.75
322	0.74	1.79
323	0.93	1.86
324	1.23	1.87
325	1.69	2.03
326	2.45	2.09
327	3.14	2.12
328	3.73	2.12
329	4.05	2.10
330	4.21	2.10
331	4.31	2.03
332	4.61	1.97
333	4.79	1.94
334	4.95	1.96
335	4.97	1.92
336	5.13	1.94
337	5.19	1.84
338	5.29	1.84
339	5.31	1.84
340	5.34	1.84
341	5.25	1.80
342	5.21	1.81
343	5.14	1.79
344	4.98	1.68
345	4.86	1.71
346	4.39	1.64
347	4.10	1.57
348	3.92	1.60
349	3.77	1.63
350	3.70	1.65
351	3.69	1.64
352	3.72	1.67
353	3.71	1.65
354	3.66	1.66
355	3.66	1.63
356	3.49	1.65
357	3.29	1.58
358	3.14	1.58
359	2.98	1.63
360	2.70	1.61

BAND	AVERAGE	STANDARD DEVIATION
361	2.47	1.55
362	2.14	1.49
363	1.91	1.34
364	1.69	1.29
365	1.37	1.12
366	1.02	0.94
367	0.69	0.80
368	0.36	0.55
369	0.11	0.37
370	0.03	0.17
371	0.01	0.08
372	0.0	0.0
373	0.0	0.0